[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
July 1942 as
Advance Restricted Report

MULTIENGINE AIRPLANE SPIN CHARACTERISTICS AS INDICATED BY MODEL TESTS IN THE FREE-SPINNING WIND TUNNEL

By Oscar Seidman and Robert W. Kamm

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

MULTIENGINE AIRPLANE SPIN CHARACTERISTICS AS INDICATED BY MODEL TESTS IN THE FREE-SPINNING WIND TUNNEL

By Oscar Seidman and Robert W. Kamm

SUMMARY

Results of recent spin-tunnel tests on models of seven multiengine airplanes are summarized and a comparison is made with corresponding results for representative single-engine airplanes loaded along the fuselage.

The multiengine airplanes give steep spins with high rates of descent and high load factors. Movement of the elevators down and of ailerons against the spin is especially effective for recovery. The rudder may be relatively less effective. For spins of single-engine airplanes loaded along the fuselage, the rudder is usually the most effective control and the ailerons should be moved with the spin to aid recovery. The difference in characteristics of the spins appears to be associated with the difference in mass distribution.

INTRODUCTION

Modern aircraft design has, in recent years, shown an increased trend toward the multiengine type with two or more engines mounted in the wings. Instances have been reported where such aircraft have been inadvertently spun, but pertinent data about the spins are lacking. The nature of the spin is of considerable interest and importance, not only from the point of view of correct control manipulation for recovery, but also from a consideration of the structural strength limitations of the airplane.

During the past few years, routine spin-tunnel tests have been conducted at the NACA on models of seven multiengine aircraft. The spins were observed to have certain common characteristics that were, as a whole, different from those generally obtained with single-engine aircraft loaded along the fuselage. The purpose of the present paper is to summarize the quantitative data for the seven models and to discuss the characteristic differences between models of multiengine airplanes and of single-engine airplanes loaded along the fuselage and their spins. Some of the data presented already have been treated qualitatively in reference 1 in a discussion of the effects of mass arrangements on spinning chracteristics. Some British observations on the subject of spins of multiengine airplanes are included in reference 2. Extensive work with models of single-engine airplanes loaded along the fuselage is reported in references 3, 4, and 5.

SYMBOLS

b	wing span, feet
S	wing area, square feet
k_X	radius of gyration about the X axis, feet
k_Y	radius of gyration about the Y axis, feet
k_Z	radius of gyration about the Z axis, feet
m	mass, slugs
R	computed radius of spin, feet
V	full-scale true rate of descent, feet per second
α	acute angle between thrust axis and vertical (approximately equal to angle of attack), degrees
ϕ	angle between lateral (span) axis and horizontal (positive when the right wing is down), degrees
Ω	full-scale anglular velocity about spin (vertical) axis, radians per second
ρ	density of air at sea level, slugs per cubic foot

DESCRIPTION OF AIRPLANES

The multiengine airplane models tested (models 1 to 7), which were all of the twin-engine type, are described in table I by means of their approximate weights and their nondimensional design characteristics. (All the airplanes were of the tractor type with the exception of model 2, which was of the pusher design.) Photographs of the models are shown in figures 1 to 7. The average values of the nondimensional design characteristics may be compared to corresponding average values presented for five pursuit-type airplanes typically representative of single-engine airplanes with the mass distributed chiefly along the fuselage. Comparison is also made in the table with the values for the model used in the tests of reference 3. The results in reference 3 are for a single-engine model having a mass distribution similar to the average for the five single-engine pursuit models loaded mainly along the fuselage but having a lower value of the relative density ($m/\rho Sb$) because lightly loaded trainers were not excluded in determining the average condition.

It has been noted that the essential differences between fuselage loaded single-engine and multiengine aircraft are as follows:

(a) In regard to external dimensions:

The aspect ratio of the wing and the horizontal tailplane is greater for multiengine aircraft; that is, if a single-engine and a multiengine model are of the same span, the multiengine model will have a smaller chord and area for both the wing and the horizontal tailplane. The multiengine model will also have a smaller maximum fuselage depth.

Multiengine aircraft are more apt to have dual vertical tail surfaces than are single-engine aircraft. As a result, the tail-damping power factor (as defined in reference 6) is likely to be higher for multiengine aircraft. Of the seven multiengine aircraft in table I, however, only four had dual vertical tail surfaces.

Present-day multiengine aircraft have large nacelles in the wing to house the engines.

(b) In regard to mass distribution:

The relative density is lower for multiengine aircraft. This factor has been found (reference 5) to have a significant effect on the spin, lower values of relative density being associated with steeper spins. The low value of relative density for the model of reference 3, which is representative of older single-engine aircraft loaded along the fuselage, thus gave somewhat steeper spins than would have been obtained for the more recent fuselage-loaded single-engine designs. For models of equal span the weight and wing loading would be lower for the multiengine model.

It is apparent from the nondimensional expressions for radii of gyration that more mass is distributed along the wing and less along the fuselage for the multiengine type. The two values b/k_X and b/k_Y, appear to be approximately interchanged for the two airplane designs and the values of the parameter $\frac{k_X^2 - k_Y^2}{b^2}$ are therefore quite different for the two types of aircraft, being positive for multiengine aircraft and negative for aircraft of single-engine design loaded chiefly along the fuselage. This parameter determines, for a given attitude and rate of rotation, the inertia yawing moment acting during a steady spin. (The actual values of the individual radii of gyration are significant only during the unsteady part of the motion, as during entry or recovery.) For multiengine designs, the parameter $\frac{k_Y^2 - k_Z^2}{b^2}$ has a larger negative value, whereas $\frac{k_Z^2 - k_X^2}{b^2}$ has a smaller positive value than the corresponding value for single-engine aircraft loaded along the fuselage. These two parameters determine the rolling and pitching inertia moments acting during the steady spin.

RESULTS

The equivalent spin altitudes at which the models were tested and the corresponding wing loading of each airplane represented are given in the following table:

Model	Airplane type	Equivalent test altitude (ft)	Wing loading (lb/sq ft)
1	YP-38	8,000	34.5
2	YFM-1	14,000	26.4
3	XF5F-1	10,000	28.4
4	XB-AB-3	20,000	35.0
5	A-20	20,000	41.0
6	XP-50	13,000	34.4
7	B-26	10,000	43.4

The results, which are presented in chart 1, were taken from the original test reports and were obtained as described in reference 7.

The load factor normal to the airplane thrust axis is computed as $1/\sin\alpha$ on the assumptions that the resultant aerodynamic force in a steady spin is approximately normal to the thrust axis and that the vertical component of the resultant force is equal to the weight of the airplane.

The steady-spin characteristics were obtained for rudders fully with the spin and elevator and ailerons covering all combinations of positions. Recovery was generally attempted by reversal of rudders from fully with to fully against the spin. In several instances, recovery was attempted by reversal of elevator from full up to full down. The data presented are for right spins. "Ailerons with the spin" means right aileron up in a right spin.

The outstanding results for each model are as follows:

(a) Model 1

Model 1 descended in a steep spin at a rate of speed in excess of 250 feet per second, full scale. Because of the high speed, few quantitative data were obtained. It was noted that the model would recover within two turns by rudder reversal from the normal spin and that it would not spin when the elevator was full down.

(b) Model 2

Model 2 spun with elevator up but would not spin with elevator neutral or down. The spins obtained were steep and had a high rate of descent (of the order of 250 ft/sec). Aileron-against spins were steeper with a higher rate of descent than aileron-with spins. The radius of spin was about 15 percent of the span and the load factor was about 2. The model would not recover by rudder reversal alone from the spins obtained with elevator up. Fairly rapid recovery could, however, be obtained by moving the elevator from the full-up to the full-down position, the rudder being left deflected with the spin.

(c) Model 3

The only control configurations for which model 3 would spin were elevator up and ailerons either neutral or with the spin. For ailerons neutral the rate of descent was over 286 feet per second, and for ailerons with, the rate of descent was 200 feet per second. For this model with the loading varied somewhat from normal, a test was made which showed the turns for recovery obtained by elevator reversal alone to be of the same order of magnitude as those obtained by rudder reversal alone.

(d) Model 4

Model 4 spun steeply with a vertical velocity exceeding 300 feet per second for all aileron settings when the elevator was full up and for the aileron-with setting when the elevator was neutral. Indications were that reversal of rudders alone would not effect recovery, but that moving ailerons and elevator against the spin would favor recovery.

(e) Model 5

Model 5 would spin for ailerons with the spin but not for ailerons against the spin. With ailerons neutral the model would spin for elevator up but not for elevator down. All spins obtained were very steep with high rates of descent. The load factors were about 2. The slowest recovery was obtained when the ailerons were set with the spin and the elevator was up. When all three controls were full with the spin, satisfactory recovery could not be obtained by reversal of either rudder alone or elevator alone.

(f) Model 6

For normal control position, the spin of model 6 was steep with the rate of descent exceeding 300 feet per second. For ailerons against the spin or for elevator neutral or down the model would not spin. For ailerons with the spin and elevator up, a flatter spin was obtained. Recovery by rudder reversal alone from this spin did not appear to be rapid. Elevator reversal alone, however, seemed more effective.

(g) Model 7

For model 7, the spins obtained were very steep (angle of attack about 25°) with very high rate of descent (exceeding 320 ft/sec). Setting ailerons against the spin reduced the tendency to spin, especially for elevator down. It was noted, however, that for this model, unlike the case for the other models, a spin was obtained for elevator down and ailerons neutral. This model differed from the others, particularly in having a higher positive value of $\frac{k_Z^2 - k_X^2}{b^2}$ and a negative value of $\frac{k_X^2 - k_Y^2}{b^2}$ (mass distribution more nearly like that of aircraft of single-engine type loaded along the fuselage). The radius of spin was from 0.1 to 0.3 of the span. Load factors obtained were of the order of 2.5. The indications were that recovery by rudder reversal alone would be rapid except from spins with all three controls set full with the spin. From this spin neither rudder reversal nor elevator reversal was effective for recovery.

DISCUSSION

The results obtained for all models were similar in that the spins with the ailerons full with the spin and the elevator full up had the poorest recovery characteristics. Setting ailerons against the spin or moving the elevator down usually led to a condition in which the model would not spin. This result indicates that the most effective control manipulation for recovery is to move all three controls to full against the spin.

All obtainable spins were at a low angle of attack, and hence the drag coefficient was low and the rate of descent was high. The high rate of descent would naturally result in high control forces.

The rate of descent increases appreciably during the recovery from a spin and also during the pull-out from the ensuing dive. Reference 8 indicates that the velocity gained during the return to level flight can be diminished by pulling out rapidly, but this procedure will give rise to high load factors. Because of the high initial velocity, skillful piloting would be required to avoid exceeding either the safe load factor or the allowable maximum airspeed for some of the larger airplanes.

The load factors during the steady spins ranged from about 1.5 to 2.7. As previously mentioned, these values are only approximate because of the assumptions involved in their computation.

It should be realized that all the results presented were obtained with small-scale models and that the range of values obtained with full-scale airplanes may be somewhat different.

The comparison between the general spin characteristics of single-engine aircraft loaded along the fuselage and multiengine aircraft in the clean condition is as follows (values for single-engine aircraft loaded along the fuselage being taken from reference 3):

Characteristic	Fuselage-Loaded Single-Engine Aircraft	Multiengine
Attitude	Steep or flat: α from 34° to 77°	Steep: α from 22° to 44°
Rate of descent	High or low: 100 to 160 fps	High: 180 to 340 fps
Angular rotation	2.6 to 4.8 radians/sec	1.9 to 3.8 radians/sec
Radius/span	0.01 to 0.16	0.07 to 0.29
Load factor during steady spin	1.0 to 1.8	1.4 to 2.7
Relative effectiveness of controls in recovery	Rudder more effective than elevator	Elevator more effective than rudder
Aileron displacement to aid recovery	With spin	Against spin

CONCLUDING REMARKS

An analysis of all existing data indicates that the differences in spin characteristics of multiengine aircraft and single-engine aircraft with the mass distributed principally along the fuselage are probably due mainly to the differences in mass distribution. The dimensional differences appear to be of secondary importance, particularly since the spin characteristics shown herein for the single-engine airplane with the mass distributed along the fuselage have been found to persist over a wide range of dimensional variations. Further specific research will be necessary, however, to isolate the important elements and to determine just which factors are responsible for the reported differences.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery from a Spin. NACA A.R.R., Aug. 1942.

2. Francis, R. H.: Interim Report of Systematic Model Research in Free Spins: Low-Wing Monoplanes. R. & M. No. 1714, British A.R.C., 1936.

3. Seidman, Oscar, and Neihouse, A. I.: Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. II. Mass Distributed along the Fuselage. T.N. No. 630, NACA, 1937.

4. Seidman, Oscar, and McAvoy, William H.: Spin Tests of a Low-Wing Monoplane in Flight and in the Free-Spinning Wind Tunnel. T.N. No. 769, NACA, 1940.

5. Seidman, Oscar, and Neihouse, A. I.: Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. V. Effect of Airplane Relative Density. Rep. No. 691, NACA, 1940.

6. Seidman, Oscar, and Donlan, Charles J.: An Approximate Spin Design Criterion for Monoplanes. T.N. No. 711, NACA, 1939.

7. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. Rep. No. 557, NACA, 1936.

8. Pearson, H. A., and Garvin, J. B.: Velocity Gained and Altitude Lost in Recoveries from Inclined Flight Paths. T.N. No. 829, NACA, 1941.

TABLE I

AIRPLANE DESIGN CHARACTERISTICS

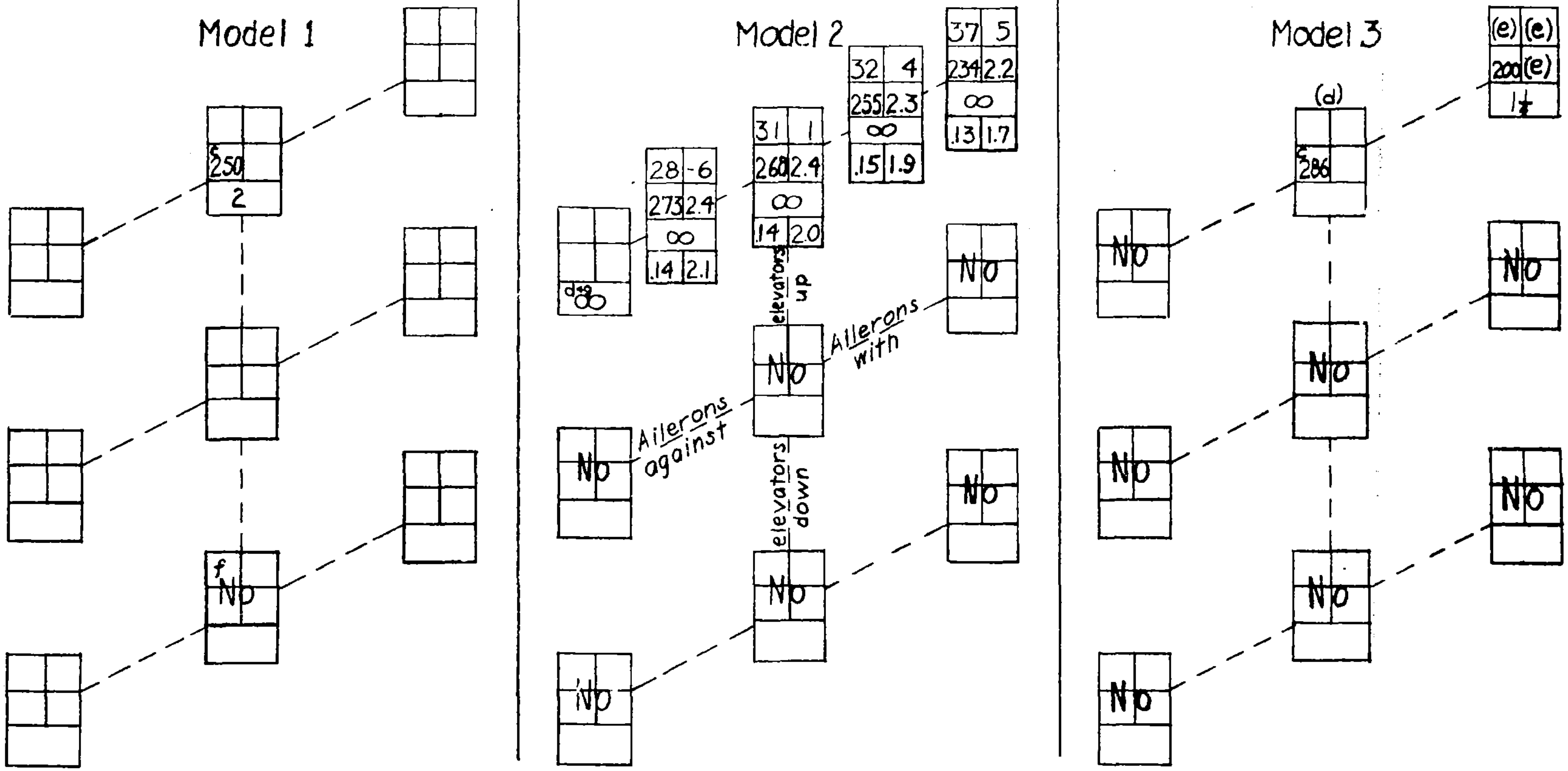
Model	Airplane	Weight (approx.) (lb)	b^2/S	c.g. (percent M.A.C.)	b/k_X	b/k_Y	b/k_Z	$\frac{k_X^2 - k_Y^2}{b^2}$	$\frac{k_Y^2 - k_Z^2}{b^2}$	$\frac{k_Z^2 - k_X^2}{b^2}$	Relative density	Tail damping power factor (a)
1	YP-38	11,300	8.30	25.4	6.86	8.27	5.34	66×10^{-4}	-204×10^{-4}	138×10^{-4}	8.66	0.00051
2	YFM-1	18,150	7.12	31.8	8.35	11.01	6.88	61	-129	68	4.93	.0001108
3	XF5F-1	8,640	5.82	23.2	6.56	8.08	5.25	76	-214	137	8.83	.001973
4	XB-AB-3	24,500	5.85	——	6.89	8.83	5.47	82	-206	123	7.14	.001735
5	A-20	19,050	8.09	21.75	8.11	9.51	6.34	41	-138	97	8.73	.000314
6	XP-50	10,450	5,83	20.5	6.45	8.69	5.15	108	-244	136	10.7	.00241
7	B-26	26,650	6.9	14.7	7.41	7.08	5.20	-18	-171	189	8.74	.000517
Average for models 1 to 7		16,963	6.84	22.89	7.23	8.78	5.66	59	-187	127	8.25	.00108
Average for 5 single engine		5,500	5.75	25.31	9.69	7.22	6.03	-78	-81.5	164	8.84	.000085
Values of reference 3		4,720	6.00	25.0	9.40	7.22	6.02	-81	-84	165	7.00	.0001605 Tail A .00001013 Tail B .0 Tail C

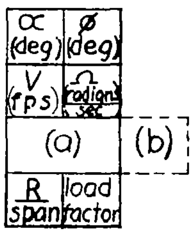
[a]Tail damping power factor calculated according to method of reference 6.

Chart 1

SPIN CHARACTERISTICS

[Landing gear retracted; flap setting neutral; rudder full with the spin prior to recovery attempt]





a Turns for recovery by full rudder reversal alone.

b Turns for recovery by full elevator reversal alone.

c High vertical velocity in excess of value noted.

d Wandering spin.

e Oscillatory spin.

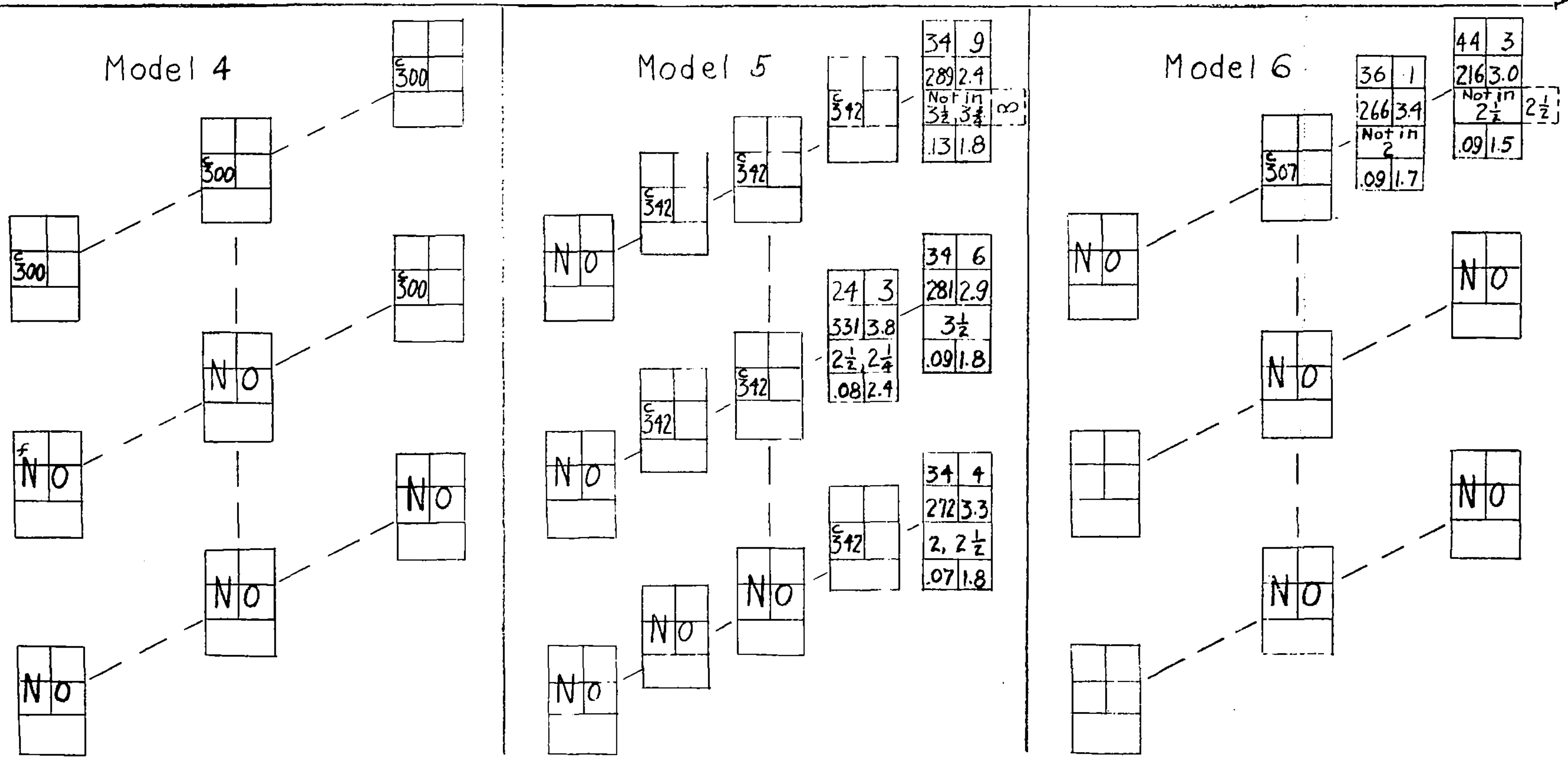
f No, indicates model would not spin.

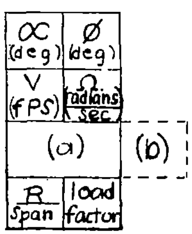
g ∞, indicates model would not recover.

Chart 1.- Continued

SPIN CHARACTERISTICS

[Landing gear retracted; flap setting neutral; rudder full with the spin prior to recovery attempt]





[a]Turns for recovery by full rudder reversal alone

[b]Turns for recovery by full elevator reversal alone

[c]High vertical velocity in excess of value noted

[d]Wandering spin

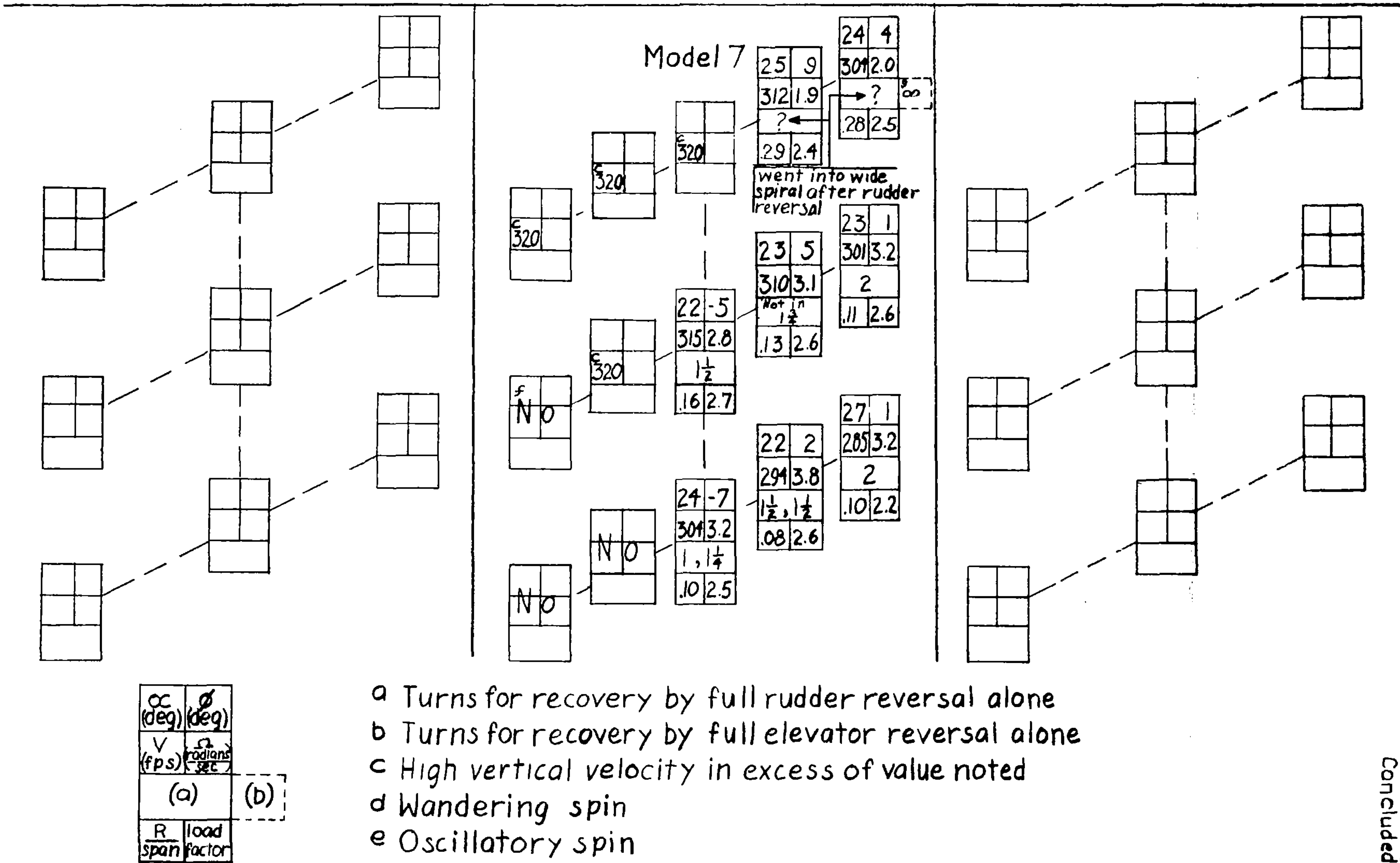
[e]Oscillatory spin

[f]No, indicates model would not spin [g]∞, indicates model would not recover

Chart 1-Concluded

SPIN CHARACTERISTICS

[Landing gear retracted; flap setting neutral; rudder full with the spin prior to recovery attempt] NACA



a Turns for recovery by full rudder reversal alone
b Turns for recovery by full elevator reversal alone
c High vertical velocity in excess of value noted
d Wandering spin
e Oscillatory spin
f No, indicates model would not spin
g ∞, indicates model would not recover

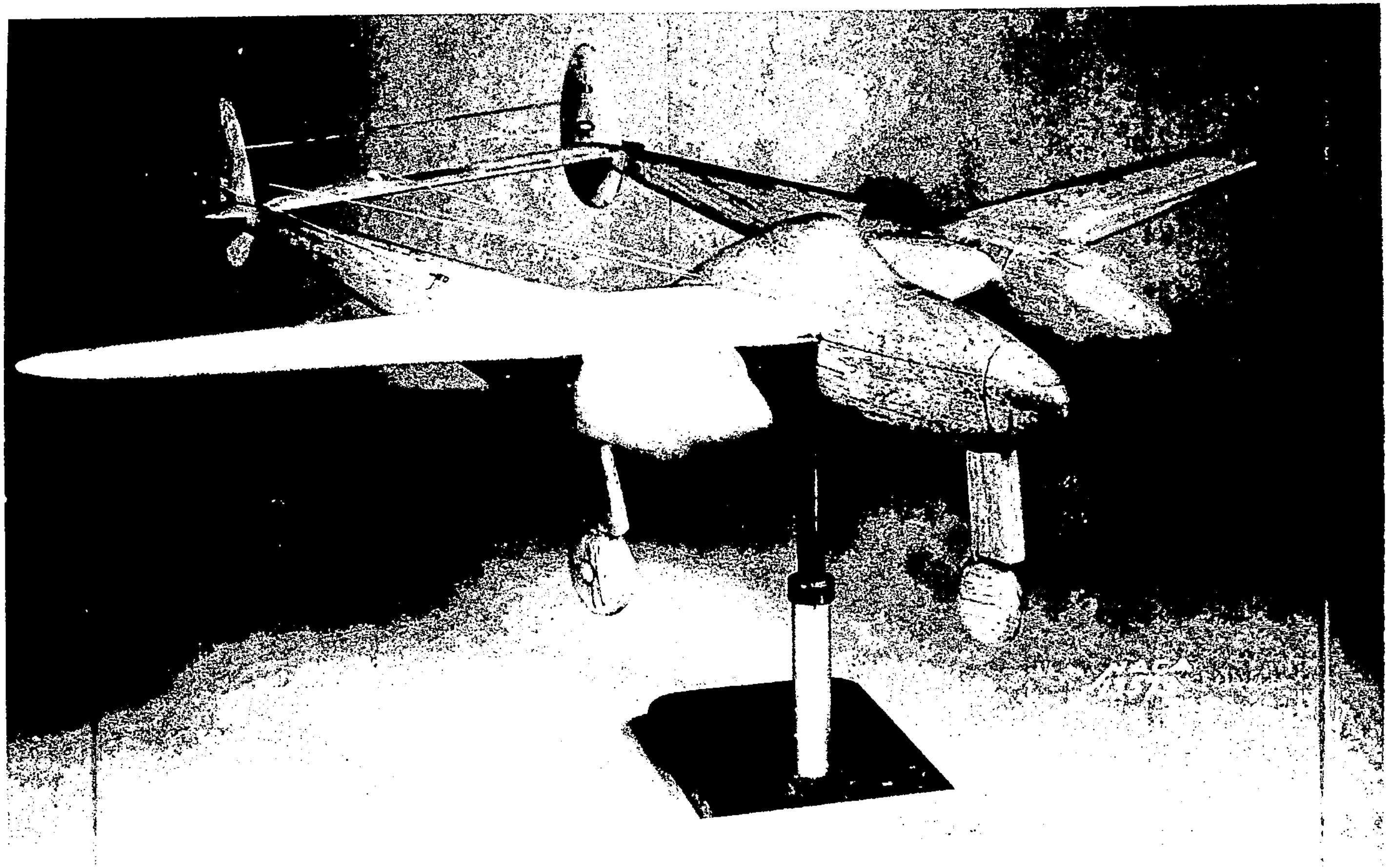


Figure 1.- Three-quarter front view of 1/20-scale model of Lockheed YP-38 airplane.

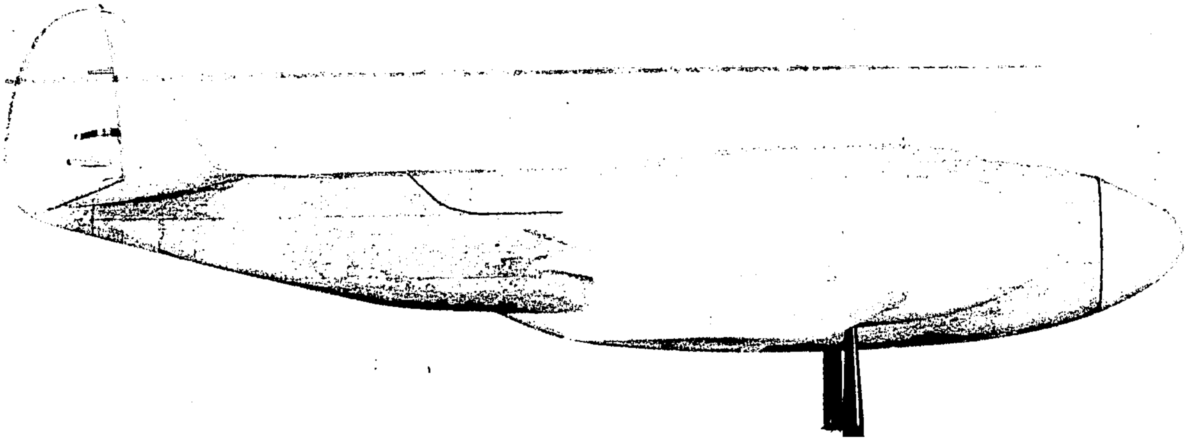


Figure 2.- Side view of 1/25-scale model of Bell YFM-1 airplane.

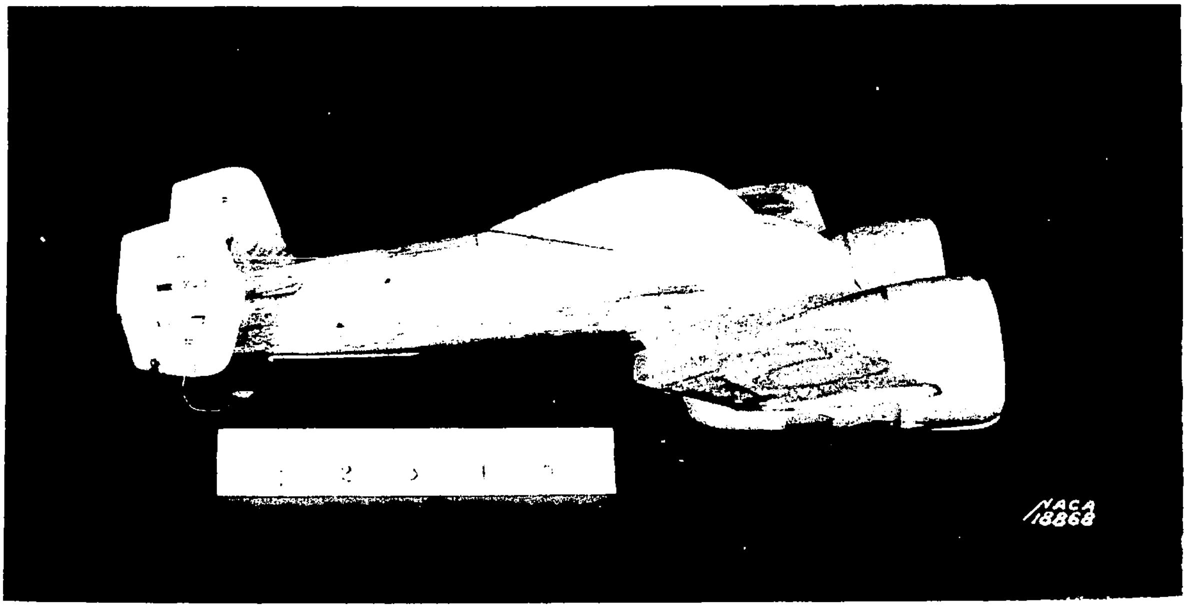


Figure 3.- Side view of 1/22-scale model of Grumman XF5F-1 airplane.

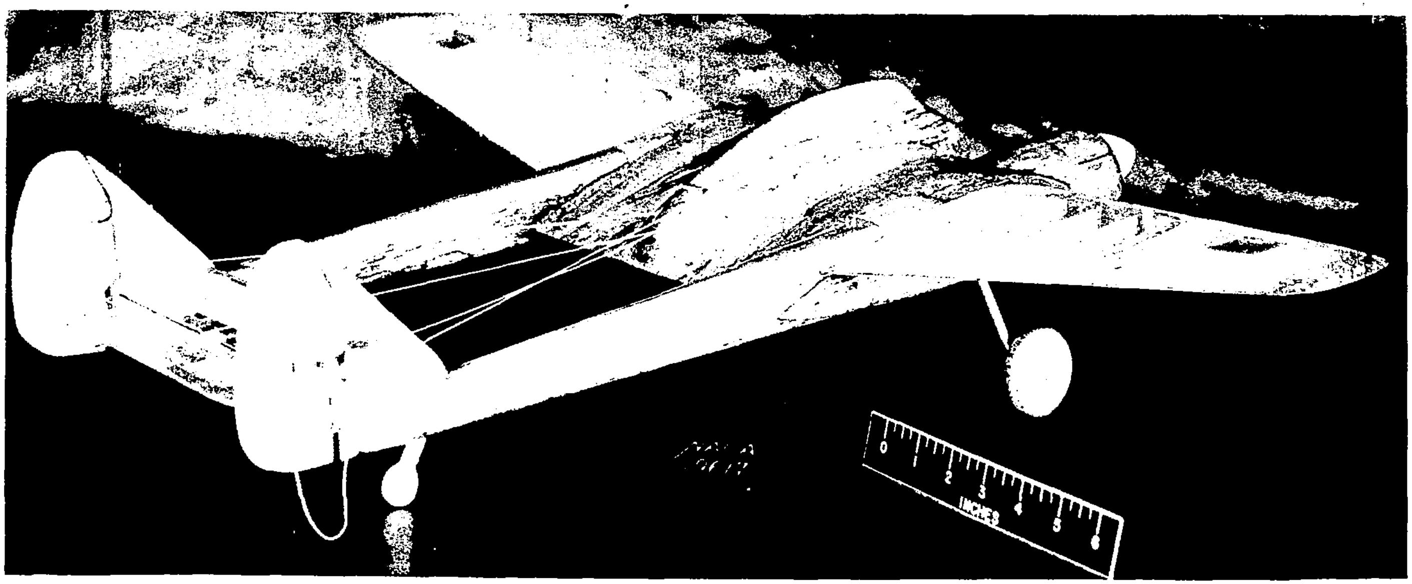


Figure 4.- Three-quarter rear view of 1/25-scale model of Burnelli XB-AB-3 airplane.

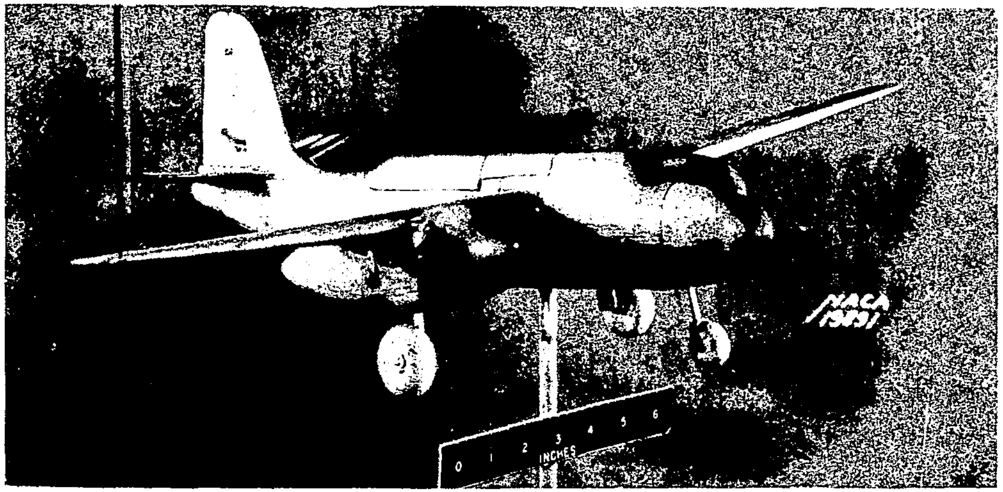


Figure 5.- Three-quarter front view of 1/30-scale model of Douglas A-20 airplane.

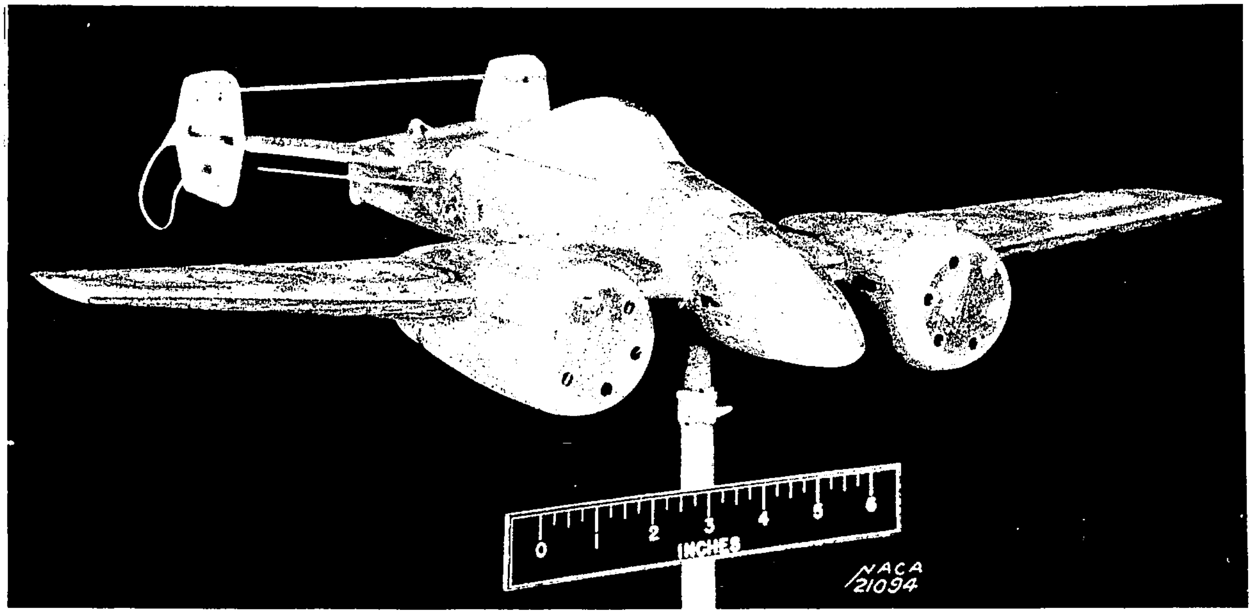


Figure 6.- Three-quarter front view of 1/25-scale model of Grumman XP-50 airplane.

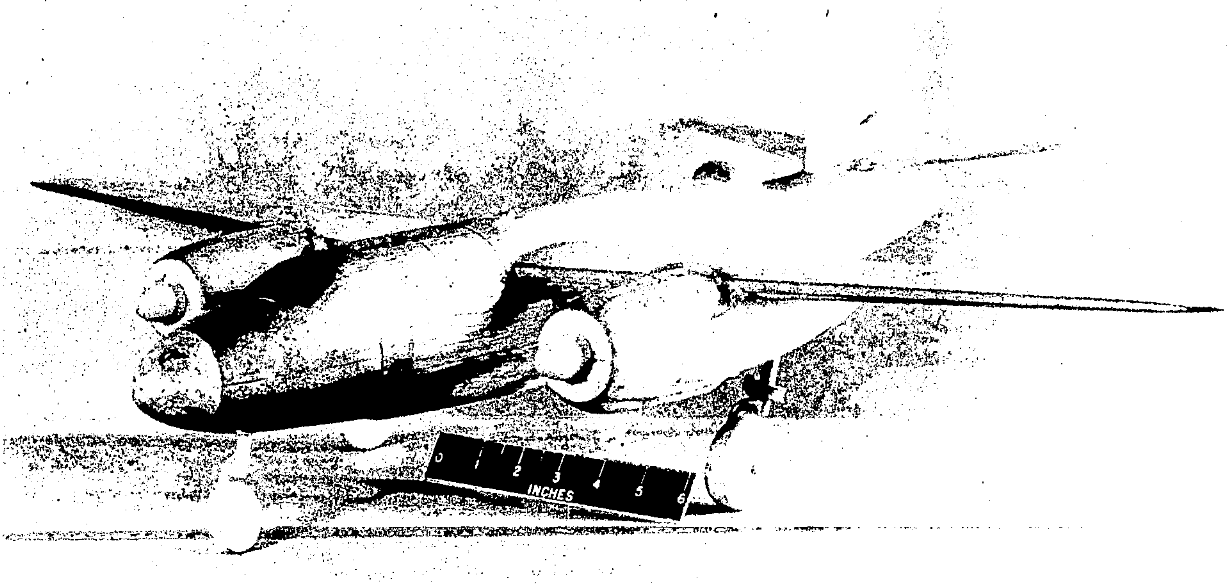


Figure 7.- Three-quarter front view of 1/26-scale model of the Martin B-26 airplane.